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Times are better for major thermoplastics
A Key Polymers Review Page 12

JULY 7, 1986

CHEMICAL & ENGINEERING

NEWS

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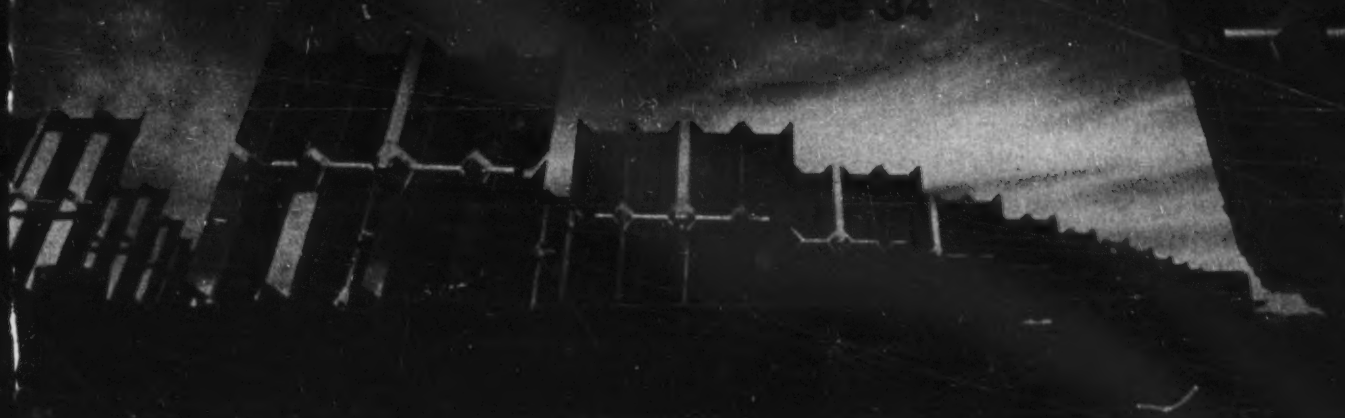
PHOTOVOLTAIC CELLS

Page 34



CHEMICAL & ENGINEERING NEWS

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JULY 7, 1986

News of the Week

■ **Industry analysts expect 1986 chemical firms' earnings to increase strongly over 1985 figures.** **Page 6**

■ **Senate committee approves bill changing current product liability laws.** **Page 7**

■ **Two science magazines have been sold recently—AAAS's *Science 86* to Time Inc., and *Scientific American*.** **Page 7**

■ **Its Command herbicide is safe, FMC says, even though it bleaches vegetation near its target plants, soybeans.** **Page 7**

■ **Nova Pharmaceutical and Celanese joint venture, Novacel, will develop controlled-release drug-delivery systems.** **Page 8**

■ **Advances in dental care include technique for removing tooth decay, new compound to fill cavities in areas where appearance is important.** **Page 8**

Business

Thermoplastics production records will be set in 1986 and the growth in output is likely to continue in 1987. **Page 12**

Mattson Instruments, founded in 1983, has 20% of FTIR market and continues to move aggressively with product development. **Page 21**

Government

Science adviser nominee William R. Graham will contend with issues ranging from scientific manpower to the space program. **Page 23**

Science

Yale chemists achieve total synthesis of *N*-acetylneuraminic acid, one of a family of acids that have potent biological activity. **Page 28**

New protein that regulates secretion of follicle-stimulating hormone in mammalian ovary discovered by two groups independently. **Page 30**

Education

Top liberal arts colleges must invest $1 billion in basic science over next decade, according to Oberlin College study. **Page 31**

Books

"**Inside the Technical Consulting Business**" is well organized, offers comprehensive coverage of the business aspects. **Page 49**

Cover: Photovoltaic panels at Arco Solar's Carrisa Plains project in San Luis Obispo County, California. The electrical output is sold to Pacific Gas & Electric Co.

Special Report

Photovoltaic cells, which may eventually replace conventional fuels for generating electricity in large-scale power plants, are out of the lab and into the marketplace. **Page 34**

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Thermoplastics Head for Production Records in 1986

Growth in output of five major thermoplastics likely will continue into 1987; profit margins have greatly improved so far this year

Bruce F. Greek, C&EN Houston

Producers of thermoplastics are on a roll. The five largest-volume thermoplastics will each set new production highs in 1986. Selling prices for these resins are significantly below levels that producers would like, but margins have greatly improved so far this year because monomer costs have rapidly declined. And producers are finding greater profitability in thermoplastics through higher operating rates and process improvements at plants.

Growth in thermoplastics output likely will continue into 1987 at nearly the current pace, barring a major economic downturn. The present major uses of thermoplastics—packaging, building and construction, and consumer products—are expected to require more of these resins as well as other plastics, as their markets expand and they gain market share at the expense of older products such as paper and glass. This market growth is resulting in production growth rates this year of 3%, for example, for polystyrene and 6% for polypropylene.

Key Polymers

Growth in production could be even greater except that competition among thermoplastics is becoming more severe and imports continue to rise. For example, some film made of the three polyolefins and, to a lesser extent, polyvinyl chloride, is going into similar end uses. Imports of low-density polyethylene and PVC are still rising and could reach 10% of consumption before the end of this decade.

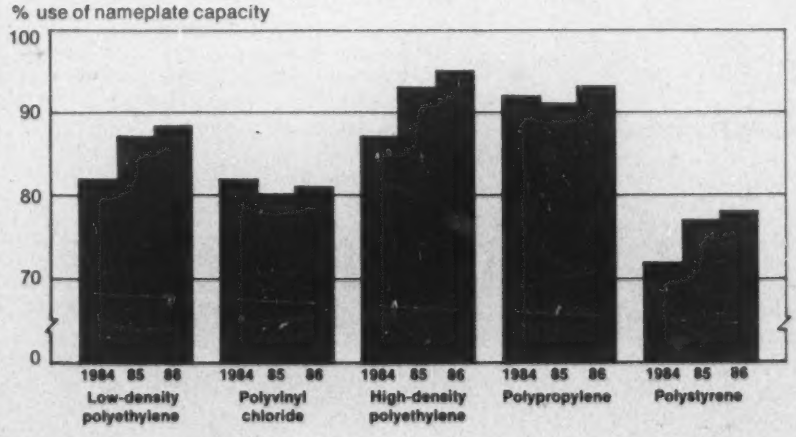
Forecasts for future growth again include conditions relating to capacity availability for some of the thermoplastics. Capacity to make polypropylene and high-density polyethylene will be pushed in 1986 to meet demand expected in both U.S. and export markets. Several expansions of capacity are under way, and others are rumored. Debottlenecking, conversion of some linear low-density polyethylene capacity to HDPE, and diversion of exports are other possibilities for increasing output. Industry sources expect a little of all of these methods to be used in 1987, just as they are this year.

The decline in overcapacity for thermoplastics isn't expected to do much for prices and margins. As prices for crude oil and gas liquids level off, and monomer prices do likewise, margins also are receding as producers cut prices to maintain their market share. If hydrocarbon feedstock prices rise and fall because of political pressures, then overall profitability in selling thermoplastics again will sag and supply-demand situations will have lesser importance.

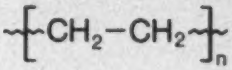
Besides changes in plant capacities, demand, and prices, thermoplastics also have had changes in ownership. So far, most of them have been for polystyrene and PVC, which are produced by a larger number of companies than the other resins. Shifts in ownership have occurred for other polyolefin plants, and more may be in the offing because of changes wrought by the decline in crude oil and gas prices. However, such changes are expected to peak this year.

For some details of the near-term outlook for the five largest-volume thermoplastics, please see the following pages.

Capacity use for major thermoplastics up this year



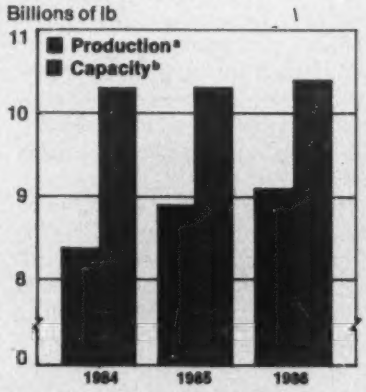
Sources: Society of the Plastics Industry's Committee on Resin Statistics, C&EN estimates



Low-density polyethylene

- ***Production rising***
- ***Capacity steady***
- ***Prices firming***

PRODUCTION/CAPACITY



a Conventional and linear low-density polyethylene. b First quarter; adjusted to account for dual capacities to make both forms.

MAJOR PRODUCERS

Chevron, Dow Chemical, Exxon, Enron (Norchem), Union Carbide

HOW MADE

Polymerization of ethylene (with comonomers as needed) at high and low pressures aided by catalysts and reaction initiators

MAJOR FABRICATED FORMS

Film (mainly for packaging) 60%, extrusion coatings 10%, injection-molded items 10%, wire and cable coverings 5%

FOREIGN TRADE

Exports—declining to about 1 billion lb, imports—rising to more than 500 million lb

PRICE

36 to 40 cents per lb, depending on grade

Low-density polyethylene output continues to grow, fueled by constantly expanding demand for plastic bags. This year, production probably will top 9.1 billion lb and possibly be more than 9.2 billion lb. Through conversion to bags, LDPE (produced in greater volume than any other plastic resin) obviously dominates the plastic film business, although other resins are making inroads.

Of LDPE production forecast for this year, more than two thirds will be made into film or be exported. At about 1 billion lb, exports of LDPE will rank a distant second as an outlet. A large number of other uses have been developed for LDPE during nearly 40 years of its commercial success in the U.S. Extrusion coatings, injection-molded items, and wire and cable coverings are among those uses but are small in proportion to use in film.

Growth in LDPE output in 1986 will range from 250 million to 300 million lb, which could turn out to be less than the volume gain expected for high-density polyethylene this year. The LDPE growth in 1986 will add about 3% to the 8.89 billion lb produced in 1985, according to the Committee on Resin Statistics of the Society of the Plastics Industry.

Capacity to make LDPE has not been a problem in recent years. In the first quarter of 1986, total capacity dedicated to making all forms of LDPE (including linear low-density polyethylene) was 10.4 billion lb. Some HDPE capacity possibly can be shifted to provide additional capacity. More likely, however, would be a shifting of LLDPE capacity to make HDPE, because demand for HDPE remains so strong. But probably no more than 500 million lb of LLDPE capacity would be shifted to HDPE, according to industry sources. Estimates of LLDPE capacity vary, but most sources put the practical total at about 3 billion lb, including 100 to 200 million lb normally included in HDPE capacity.

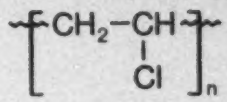
Consequently, if production of all forms of LDPE totals 9.1 billion lb in 1986 and nameplate capacity is 10.4 billion lb, then the operating rate will be merely 88%. But if 0.5 billion lb of capacity that produces mostly HDPE are excluded, then the operating rate rises to more than 90% of the reduced nameplate capacity.

Nevertheless, there is overcapacity for LDPE, keeping pressure on selling prices. Prices for major-volume grades range from 27 to 29 cents a lb, which is typically a third off list prices. The overcapacity also hinders efforts to raise prices, even as ethylene prices are pushed higher. The overcapacity won't end soon, because new capacity has been announced with on-stream dates for 1987 and because technological advances are debottlenecking existing plants more rapidly than would otherwise be the case.

The pressure exerted by converters of polyethylene film long ago has led major producers such as Dow Chemical, Mobil, and Union Carbide to enter the consumer market by selling various kinds and sizes of bags and films. Their marketing costs are high, but demand continues to grow, providing a steady outlet, and allowing them to have considerable economies from a more-even operation of monomer and polymer plants.

Several other fabricated forms of LDPE are growing well but from small bases. Of the smaller volume uses, extrusion coatings and injection molding have shown gains this year. The major part of extrusion coating uses is in making 1-qt milk cartons and other food containers.

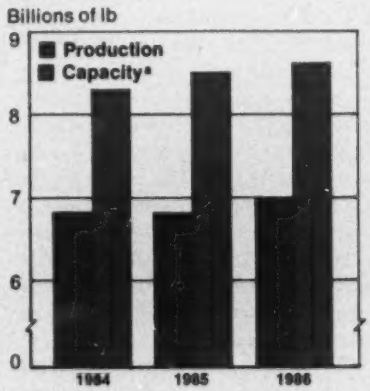
Exports of LDPE could decline, especially as the various new LLDPE plants start up in various parts of the world. So far, exports appear to be down about 10% this year, or at a 100 million to 150 million lb annual rate. The decline in exports, which must be absorbed by the domestic market, could be the major reason that LDPE is growing at only about 3% in 1986.



Polyvinyl chloride

- *Production up again*
- *Capacity up a bit*
- *Prices leveling*

PRODUCTION/CAPACITY



a First quarter.

MAJOR PRODUCERS

Formosa Plastics, Georgia Gulf, B. F. Goodrich Chemical, Occidental Chemical, Shintech

HOW MADE

Polymerization of vinyl chloride (sometimes with comonomers) initiated by free radicals

MAJOR FABRICATED FORMS

Pipe 45%, other extrusions 25%, calendered items 10%, molded items 5%

FOREIGN TRADE

Exports—holding at about 300 million lb, imports—rising to possibly more than 300 million lb

PRICE

37 to 50 cents per lb, depending on grade

Polyvinyl chloride output will increase in 1986 after stagnating for two years in the wake of a major production jump in 1983. Output in 1986 will top 7 billion lb, after holding at just below 6.8 billion lb in 1984 and 1985. This year's growth stems mostly from increased consumption of PVC in its major markets, particularly pipe and fittings and other construction components.

The increase in production of PVC expected during 1986 could be as much as 300 million lb but likely will be closer to 250 million lb. That increase of about 4% is small for a commodity resin of this size but for many organic chemicals would be large. Because imports of a host of different consumer products made from PVC hold down fabrication in the U.S., output likely will not exceed 7.1 billion lb.

As 1986 began, PVC capacity totaled 8.6 billion lb. Because of both debottlenecking and actual plant additions, capacity has been increasing. However, no major additions to capacity are expected this year.

Capacity utilization will not change much because the expansions during the past two years have been offset by increased output. Should production in 1986 slightly exceed 7 billion lb, the operating rate will reach 81% of estimated nameplate capacity.

Capacity ownership has been changing as capacity has increased. The largest recent shift in ownership occurred when Occidental Chemical bought Tenneco Chemical's PVC operations, a transaction involving some 700 million lb of annual capacity and completed during the second quarter.

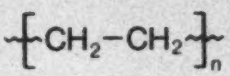
It is debatable whether new ownership for a sizable portion of PVC capacity will improve profitability in making the resin. Efforts have been under way to restore selling prices to the 30 to 33 cent-per-lb range for most large-volume grades of PVC, up 2 to 3 cents a lb from levels reached during May. Whether the June prices will hold depends on what happens to ethylene during the third quarter and to previously announced price increases for chlorine, which accounts for more than half of the weight of the monomer.

Some of the price increases of PVC likely will result from monomer price increases passed along. Vinyl chloride producers have had some mechanical problems that have cut output periodically during the second quarter. Those problems, plus strong exports of both vinyl chloride and its precursor, ethylene dichloride, may have reduced polymer supply at a time when demand was strong, especially for pipe-grade resins.

The net of exports of vinyl chloride over imports for the first four months of 1986 was more than 420 million lb. Production during the same period is estimated at about 2.7 billion lb, suggesting that net exports account for more than 15% of production. With the production problems and high exports, vinyl chloride producers may be able to pass on their cost increases. PVC producers then would be forced to do the same. That could cause most of the newly announced price increases to hold for part of the third quarter, even while production declines at the end of the major demand cycle for pipe-grade resins.

PVC prices hinge on pipe-grade resins because those resins account for such a large share, nearly 45%, of U.S. consumption of the polymer. Large additional quantities of PVC go into fittings and other components used with pipe and tubing. Use of PVC pipe has been strong, causing inventories to be drawn down this spring.

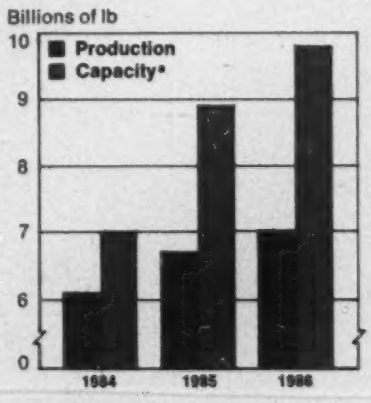
The negative side of the PVC outlook involves the large exports of monomer. Much exported vinyl chloride returns to the U.S. in the form of finished nondurable goods, such as luggage, shoes, and other consumer products made of PVC. Such product imports are forecast to continue to rise, reducing U.S. consumer consumption of PVC while industrial uses keep growing.



High-density polyethylene

- ***Production up well***
- ***Capacity up a bit***
- ***Prices holding***

PRODUCTION/CAPACITY



a First quarter; includes capacity capable of making either high-density or linear low-density polyethylene.

MAJOR PRODUCERS

Du Pont, Phillips, Soltex, Union Carbide, U.S.I.

HOW MADE

Polymerization of ethylene at low pressures aided by metallic salts and alkyls

MAJOR FABRICATED FORMS

Blow-molded items (mainly containers) 40%, injection-molded items 25%, film and sheet 10%, pipe and conduit 10%

FOREIGN TRADE

Exports—holding at about 800 million lb, imports—small, less than 50 million lb

PRICE

43 to 50 cents per lb, depending on grade

High-density polyethylene output will increase again this year because demand by most major-volume end uses as well as exports is rising. Smaller-volume uses—film, for example—also are growing strongly, spurred by product development leading to the capture of markets previously held by other materials.

The gain in HDPE production in 1986, however, will drop to half 1985's gain, according to most current forecasts. Production likely will top 7 billion lb for the first time, up more than 300 million lb, or 5%, from last year's 6.67 billion lb estimated by the Committee on Resin Statistics of the Society of the Plastics Industry. Output in 1985 was up about 600 million lb over 1984, the gain resulting from substitution of HDPE for other materials used in packaging and many other end uses.

Apparently capacity is sufficient for the HDPE production forecast for 1986. Because several producers have the capability to switch between linear low-density polyethylene and HDPE, estimates of actual capacity range from about 7.4 billion to 9.9 billion lb, a spread of 2.5 billion lb. Industry sources indicate that the HDPE production volume made from the low-pressure capacity that is interchangeable between LLDPE and HDPE likely will be 500 million to 1 billion lb. If total nameplate HDPE capacity is as low as 7.4 billion lb, then the average operating rate in 1986 will be 95%. Nameplate capacity more likely is 7.7 billion to 7.9 billion lb, which would reduce the operating rate to the low 90% range.

An operating rate of 90 to 95% clearly indicates that demand for HDPE continues to be strong and that prices will hold up well. At a selling price of 30 to 33 cents per lb, HDPE ranks above both low-density polyethylene and LLDPE, priced below 30 cents a lb. Under pressure from lower crude oil prices and lower-than-expected demand for fuel products, proposed ethylene price increases may not last during this month. However, if they do, producers of HDPE may be able to pass on their raw material cost increase.

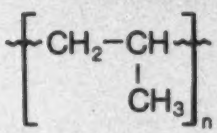
Molded products, mostly bottles or containers of one kind or another, take nearly two thirds of U.S. HDPE consumption. Bottles for milk (mostly 1-gal size), juices, syrup, and water are the largest-volume molded end products, and almost all are blow molded. For nonfood uses of molded bottles, motor oil containers have received much attention recently, as many oil companies switched from cans made entirely of metal, or fiber-board and foil laminates with metal ends, to HDPE 1-qt and 5-qt bottles. Rapid growth may be over for this use of HDPE, as well as for containers for household bleach, detergents, and various other nonfood products, because HDPE now practically dominates the market.

Industrial containers made of HDPE, both blow-molded and injection-molded, now are a major growth area. Some uniformity in design and changes in shipping regulations have helped to capture markets from steel containers in 5-gal and larger sizes. Resistance to corrosion can offset higher costs and difficulties in adapting existing filling equipment to use of HDPE containers. The capture of 1-gal paint cans from steel is being attempted, but success on a cost-competitive scale remains in the future.

Film use, at less than 10% of HDPE consumption, has been boosted by the shift from paper bags in the grocery and other retail areas. Frequently, the film used for bags is made of a blend of HDPE and another resin, often LLDPE, making estimates of the potential use in film difficult.

Exports at some 800 million to 850 million lb forecast for 1986 account for more than 10% of production. They have been expected to decline as new capacity for HDPE starts up in various parts of the world, but the new capacity quickly has become fully utilized, and that tends to shore up exports. Possibly after 1986 exports may begin to decline.

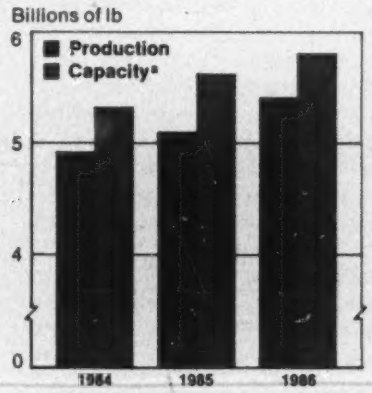
Key Polymers



Polypropylene

- ***Output up steadily***
- ***Capacity easing***
- ***Prices steady***

PRODUCTION/CAPACITY



[a] First quarter.

MAJOR PRODUCERS

Amoco, Exxon, Himont, Shell, USS Chemicals

HOW MADE

Polymerization of propylene (sometimes with comonomers) aided by metallic salts and alkyls

MAJOR FABRICATED FORMS

Fibers and filaments 35%, injection-molded items 30%, film 10%

FOREIGN TRADE

Exports—rising to about 1 billion lb, imports—small and holding at about 10 million lb

PRICE

45 to 60 cents per lb, depending on grade

Polypropylene producers continue to enjoy high capacity utilization despite numerous rounds of expansions. Polypropylene production in 1986 is forecast to increase as much as capacity rose last year. Capacity in 1986 will expand about 200 million lb, the same as the expansion in 1985. As a result, U.S. nameplate capacity will reach 6 billion lb a year as 1987 begins.

Polypropylene output this year will exceed 5.4 billion lb, up some 300 million lb, or 6%, from the 5.14 billion lb produced in 1985, according to the Committee on Resin Statistics (CRS) of the Society of the Plastics Industry. Some market observers forecast that production will be up more than 8% this year. However, despite capacity additions due on stream in 1986 and strenuous debottlenecking achieved through catalyst and other technological changes, capacity may be insufficient to make such a volume.

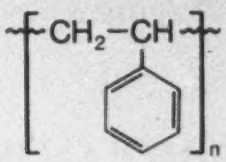
If production totals 5.4 billion lb in 1986 and nameplate capacity for the year is 5.8 billion lb, then the average plant operating rate will be more than 93%. Should production total 5.6 billion lb and additions during the year bring nameplate capacity to 5.9 billion lb, the operating rate would be 95%. At that operating rate, resistance would be strong to stop production to make changes in grades; thus, shortages of certain less common grades might result.

Even at 1985's high plant operating rate of about 91%, producers of polypropylene apparently could not meet demand. Sales and use of polypropylene in 1985 totaled 5.28 billion lb, according to CRS. Use exceeded production 135 million lb, or 2.5%. That drawdown of inventories might be replaced partially in 1986. Nevertheless, supplies will remain tight during most of the year.

Tightening supply has prompted price increases for polypropylene. After somewhat successful efforts late in 1985 to raise prices, declining crude oil and gas liquids prices again forced polypropylene prices down. The large reduction of use of lead alkyls in gasoline has lowered the value of propylene to refiners and has led refiners to try to sell more to chemical and polymer markets. That puts additional pressure on propylene prices. Consequently, polypropylene producers have been forced to pass through most of their raw material cost savings. Recent prices range from 31 to 33 cents per lb for the large-volume grades, down 4 to 7 cents per lb from the beginning of the year and well off from list prices. The outlook for price increases depends partly on gasoline demand and partly on ethylene prices. If ethylene prices increase (as producers have wanted) beginning this month, then propylene and polypropylene prices could rise as well, although probably not to the same degree. Until feedstock propylene costs rise significantly, polypropylene prices will hold at about their present levels.

Relatively low prices at a time when supplies are tight stem partly from the large exports of polypropylene. In 1985, exports totaled some 875 million lb, or 17% of production. They may rise to as much as 1 billion lb in 1986. Exporters hope to retain their markets by low prices that compete with foreign producers, some of which have new plants.

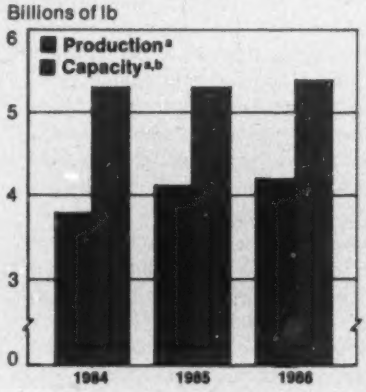
Increased U.S. consumption of polypropylene will account for most of the other 175 million lb of added output in 1986. Some of the additional production may go into inventory, but most will go into more of the same major-volume end products that were made in 1985. Those big end uses—film, fibers and filaments, packaging, transportation items (mainly battery cases, but also automotive trim parts), and consumer products—will continue to grow at fairly high rates, often spurred or reduced by fashion and innovation. Among the small uses, thermoplastic olefinic elastomers could grow fast enough to soon have an important effect on polypropylene demand.



Polystyrene

- ***Output up modestly***
- ***Capacity debottlenecked***
- ***Price forced up***

PRODUCTION/CAPACITY



a Straight and rubber-modified resins.
b First quarter.

MAJOR PRODUCERS

Arco Chemicals, Dow Chemical, Fina Chemicals, Huntsman Chemical, Monsanto

HOW MADE

Polymerization of styrene using initiators

MAJOR FABRICATED FORMS

Molded items 45%, extruded items 35%, expandable beads 15%

FOREIGN TRADE

Exports—small, may rise above 100 million lb, imports—small, about 30 million lb

PRICE

48 to 52 cents per lb; expandable beads cost about 20 cents more per lb

Unstable selling prices for both polystyrene and styrene (as influenced by benzene prices) now concern producers more than lack of a high-growth market for polystyrene. Overcapacity is continuing to keep pressure on polystyrene prices and add to pricing problems. No new high-growth market to ease the pricing problems is on the horizon—at least in part because current low margins in making polystyrene don't go very far in supporting product research and development.

Lower benzene prices, announced in June (to be effective then or on July 1), may put pressure on the price increases for various kinds of polystyrenes. Increases of 2 to 3 cents per lb for crystal and impact polystyrenes would have pushed most selling prices into the range of 32 to 35 cents per lb, which still is well below posted list prices.

When gasoline and crude oil prices were increasing in May, spot prices for benzene began to exceed contract prices of 80 cents per gal. Benzene contract prices were forecast to reach 90 cents per gal by July 1, and possibly higher, pulling prices for styrene, produced by alkylation of benzene with ethylene, higher as well. However, the gasoline demand increase of early summer has been less than expected, and prices for most aromatics (key ingredients in gasoline to provide high octane values) haven't increased as forecast. The result appears to be that price increases for polystyrene caused by efforts to pass through raw material price increases will erode this month.

Strong demand could help shore up polystyrene price increases. During the first quarter, polystyrene production was up 4% over that of the same 1985 quarter; it traditionally has been higher during the first half of the year. An increase of about 3% is forecast for all of 1986, but that level of production will not have a large enough impact on an overcapacity of more than 20% on a nameplate basis to help prices.

Second-quarter production of polystyrene is estimated to outstrip that in the first quarter. A particularly strong second quarter is traditional for polystyrene because many plants are shut down during the third quarter for vacations and maintenance, and additional inventory is required to meet demands.

Forecasts for production of polystyrene this year cluster around 4.2 billion lb, which is slightly higher (about 3%) than the 1985 production of 4.05 billion lb reported by the Committee on Resin Statistics of the Society of the Plastics Industry. Capacity to make polystyrene, as 1986 began, was 5.4 billion lb and unlikely to increase much this year. The operating rate for the year, therefore, will be 78% of nameplate capacity, up slightly from last year's rate. Polystyrene has the lowest capacity utilization of the major-volume thermoplastics.

In 1986, all of the major end uses of polystyrene likely will hold their share of the market. Many—such as packaging and other disposables, electronic and electrical components, and construction materials—are well established and will depend on the general economy for growth. About one third of polystyrene consumption in the U.S. stems from packaging, with uses of the packages ranging over most consumer products such as cups, egg cartons, and berry boxes. Growth in packaging uses will be low, probably holding at 2% annually.

Other use categories—housewares and furniture items, toys and other recreational items, and food serviceware, as well as electronics and construction—require 350 million to 500 million lb each of polystyrene. Except for the electronic components area, none of those uses are growing very fast. Miscellaneous uses of polystyrene account for about 10% of consumption, and none of those small uses will grow fast enough to pull the resin back onto a high growth rate track during this decade.

Top Liberal Arts Colleges Need More Money for Basic Science

Oberlin College study says schools must invest $1 billion over next decade to maintain and enhance their present strong position in science

If the nation's top liberal arts colleges are to maintain and enhance their present strong position in basic science, they must invest about $1 billion—over and above current commitments—during the next decade. That's perhaps the most important message in "Maintaining America's Scientific Productivity: The Necessity of the Liberal Arts Colleges," a recent report by provost Samuel C. Carrier and research director David Davis-Van Atta of Oberlin College.

Preliminary findings from the new report were presented at the Second National Conference on the Future of Science Programs at Liberal Arts Colleges. Some 50 college presidents from 19 states attended the meeting, which was held last month at Oberlin. The final version of the report will appear this fall.

At the first such meeting last year, Carrier and Davis-Van Atta presented another report, "Educating America's Scientists: The Role of the Research Colleges." That report pointed up just how important a role those 50 colleges and other U.S. liberal arts colleges played in keeping the scientific pipeline full.

For example, although nationally there has been "significant erosion in freshman interest in the basic sciences," the 50 schools participating in the conference have actually increased their share of freshmen intending to major in a science. That share now almost equals the share of "the highly selective private universities."

Moreover (according to the 1985 report), those same 50 colleges' science graduates go on to earn doctorates in a significantly higher proportion than do graduates of either the Ivy League schools or the 20 top-rated research universities. One of the main reasons for this success has been the increased number of women interested in science. Women now form a majority of science graduates at those 50 liberal arts colleges, with their numbers rising 14% in the past 10 years.

However, those 50 colleges, compared with the private research universities, are largely tuition-dependent, endowment-poor, and underfunded by both government and industry. Although the colleges produce 7% of the nation's basic science undergraduate degree recipients, they receive less than 0.5% of National Science Foundation expenditures. And, the report notes, "Enrollment and funding are moving in opposite directions."

The 1986 study reflects a continuation of those trends. In 1985, it notes, the number of freshmen intending to major in a science increased slightly, to nearly 30% of the total.

One of the main reasons the liberal arts colleges succeed in attracting potential science majors is their faculties. Typically, they are "university caliber," with members actively engaged in research. However, those "productive, practicing scientists" also teach students at all levels. In addition, students themselves are also actively engaged in research. Nearly 30% of all scientific articles from the colleges are jointly authored by undergraduate students and faculty mentors.

Carrier and Davis-Van Atta profile the liberal arts college science faculties: Overwhelmingly male (89%). Virtually all white (96%). Most (69%) are tenured. Almost all (97%) are full-time employees. Average age is 44.1 years—"relatively old," according to the study.

The study notes that the percentage of women science faculty members has nearly doubled over the past 10 years, from 5.8% to 11%.

Liberal arts science faculties are:

- **Overwhelmingly male (89%)**
- **Virtually all white (96%)**
- **Mostly tenured (69%)**
- **Almost all full-time (97%)**
- **Relatively old (average age 44)**

Where the billion would go

$ Millions	Capital needs
Additional faculty positions	**$ 369.1**
Faculty salary and benefits	116.2
Support staff salary and benefits	23.1
Materials and supplies	33.2
Facilities construction	152.9
Facilities maintenance	43.7
Maintain and enhance teaching and research	**531.8**
Starter grants	58.2
Probationary period research leaves	27.2
Competitive faculty compensation adjustment	152.2
Student research assistants	118.3
Scientific equipment and instrumentation	175.9
Maintain and enhance labs and classrooms	**$ 150.0**
Replace outdated buildings	48.2
Renovate aging buildings	101.8
TOTAL	**$1050.9**

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However, the percentage of minorities is "shockingly low." For example, the number of black science faculty members is less than 1%.

"Even though this dismal record is no worse than that of most research universities, it is nonetheless unacceptable," says Oberlin president S. Frederick Starr. "The leading liberal arts colleges should undertake a special effort to train and attract black faculty members in the basic sciences."

As to scientific instrumentation and equipment, a wealth of detail in the study suggests that the liberal arts colleges, like other institutions of higher education, are getting along but would like to have more and better equipment. Classrooms and laboratories don't seem to be a major problem. The study does note, however, that the average age of buildings is almost 50 years and that only 12% of the buildings are less than 10 years old.

All in all, a pretty good record for the 50 colleges. But, the study asks, "What is needed to sustain and build this record?" The answer: "About a billion dollars." That answer assumes a 1.1% annual growth in teaching staff and also in support facilities and personnel. That translates into a capital requirement of about $369 million.

In addition, $531 million will be needed to "maintain and enhance teaching and research" and another $150 million to "maintain and enhance laboratories and classrooms."

Carrier and Davis-Van Atta note that computing what are actually annual costs (for example, the cost of maintaining additional faculty members) in terms of the capital needed to support those costs is a simplifying assumption. But they believe it's a reasonable assumption, since such expenses do indeed represent a claim on capital, even though they don't add to the capital base of the school.

"The fundamental conclusion of this study is that the colleges, individually and collectively, should launch campaigns to reach the billion dollars needed," Starr observes. "Just how this formidable enterprise is to be organized and undertaken is a question that looms large."

Ward Worthy, Chicago

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